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Simulator Motion

John A. Boldovici
U.S. Army Research Institute

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This review analyzes the arguments for and against using various methods of force motion cuing in land-vehicle and aircraft simulators. Research literature was reviewed and opinions were solicited from 31 authorities, 24 of whom replied. Analysis of the literature and of the reasons given by the authorities for and against the use of force motion cuing indicated the following: (1) No transfer of training data support using motion-based rather than fixed-base simulators; (2) the absence of supporting data may be due to the unknown characteristics of motion used in transfer research, safety considerations that preclude conducting definitive transfer of training experiments, and deficiencies in experiments that lead to inadequate statistical power; and (3) objective examination of the effects of force motion cuing on transfer to land vehicles and aircraft requires developing and using reliable and safe tests for assessing the performance of tasks that cannot safely be performed in parent vehicles. In the absence of transfer data demonstrating the superiority of fixed-based or motion-based simulators, analyses to identify discriminative stimuli are recommended. The report presents algorithms for deciding for which tasks the

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use of force motion cuing in training is likely to facilitate transfer to parent vehicles and for deciding whether seat shakers, g-seats, or motion bases are sufficient to provide discriminative stimuli for task performance.

Technical Report 961

Simulator Motion

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Training Simulation

FOREWORD

The U.S. Army Project Manager for Training Devices (PM TRADE) and PM TRADE engineers requested the assistance of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) in determining motion requirements for land-vehicle and aircraft simulators. In response to those requests, ARI's John A. Boldovici reviewed research articles and analyzed the arguments for and against force motion cuing given in interviews and correspondence with 24 simulator-motion authorities. The analyses led Dr. Boldovici to conclude that research results are insufficient to support decisions about whether to use force motion cuing in land-vehicle and aircraft simulators, and that additional research on transfer from simulators to parent vehicles cannot resolve the issue. The reasons involve the negligible practical value of research results that show no differences in transfer based on using and not using motion in training and the infeasibility of reproducing dangerous tasks in parent vehicles for purposes of conducting transfer research. In lieu of relying on the results of necessarily inconclusive research on transfer to parent vehicles, the author recommends analyses to identify discriminative stimuli for task performance. Algorithms are presented for deciding for which tasks the use of force motion cuing in training is likely to facilitate transfer to parent vehicles and for deciding whether seat shakers, g-seats, or motion bases are sufficient to provide discriminative stimuli for task performance.

The work described in this report was performed under the PM TRADE-ARI Memorandum of Understanding entitled "Advanced Technology for the Design of Training Devices." Earlier drafts of the report, a brief position paper based on the report, and progress reviews were given to Mr. Curless, Mr. Kuma, Mr. Strano, and other PM TRADE engineers; and to the product manager for Air Combat Training Systems, LTC Russell. Copies of the position paper were given to PM TRADE's Chief, Research and Engineering Management, Mr. Goodman, for distribution to engineers and product managers at PM TRADE. The results presented here also were briefed to the Deputy PM TRADE, Mr. Williams, in response to questions about motion requirements for the AH-64 simulator. Replies to requests for the position paper and for drafts of the report have been sent to Army and Navy engineers and researchers, most recently in connection with inquiries about simulator-sickness. Copies of the report also were supplied to all contributors to the report, representing the Air Force, private industry, consultants, universities, and the U.S. Army Research Institute Aviation Research and Development Activity.

Edgar M. Johnson

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SIMULATOR MOTION

EXECUTIVE SUMMARY

Requirement:

This review addresses the requirement to analyze the arguments for and against using various methods of force motion cuing in land-vehicle and aircraft simulators.

Procedure:

Research literature was reviewed and opinions were solicited from 31 authorities, 24 of whom replied. The replies were examined to identify reasons for and against the use of force motion cuing. They were discussed in light of existing data and of other research considerations.

Findings:

The findings in this report include the following: (1) No transfer of training data support using motion-based rather than fixed-base simulators; (2) the absence of supporting research data may be due to the unknown characteristics of motion used in transfer research, safety considerations that preclude conducting definitive transfer of training experiments, and deficiencies in experiments that lead to inadequate statistical power; and (3) objective examination of the effects of force motion cuing on transfer to land vehicles and aircraft requires developing and using reliable and safe tests for assessing the performance of tasks that cannot be practiced safely in parent vehicles. Logical cases for using force motion cuing in training can be made for some conditions: (1) The motion creates distractions or is a source of task difficulty that must be ignored or overcome during task performance; (2) the motion provides an alert that gives operators time to perform tasks that are time constrained and dangerous; and (3) the motion provides discriminative stimuli for task performance. In the absence of transfer data demonstrating the superiority of fixed-base or motion-based simulators, analyses to identify discriminative stimuli are recommended. Algorithms are presented for deciding for which tasks the use of force motion cuing in training is likely to facilitate transfer to parent vehicles, and for deciding whether seat shakers, g-seats, or motion bases are sufficient to provide discriminative stimuli for task performance.

Use of Findings:

The findings in this report can be used (1) to evaluate arguments for and against using force motion cuing in land-vehicle and aircraft simulators, and (2) as bases for analyses and research to identify tasks for which using force motion cuing in training is and is not likely to facilitate transfer to parent vehicles.

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SIMULATOR MOTION[1]

Introduction

The U.S. military is buying and will continue to buy millions of dollars worth of land-vehicle and aircraft training devices. Whether to use motion bases is an issue that recurs and shows little promise of early resolution. Persons who do research with aircraft simulators have disagreed for many years about whether motion platforms are necessary or desirable. An example of the controversy is the cost-benefit assessment for C-17 transport simulators by Gebman et al. (1986) and Lintern's (1987) rebuttal of Gebman et al.'s reasons for recommending motion platforms.

Devices being purchased or under consideration by the U.S. Army include networked combat simulations with land vehicles and helicopters; motion based M1 Tank driver trainers; fixed base truck driving simulators under consideration for purchase by the U. S. Army Transportation School; Future Infantry Fighting Vehicle simulators; the Aviation School's Light Helicopter simulator; and various land-vehicle simulators that may be included in the Armor Systems Modernization program.

The planning sessions that precede contract awards for training devices are numerous and are attended by persons who have various expertise. Debates about whether to buy motion bases often include anecdotes, misinterpretation of research results, and incomplete knowledge of the research issues that underlie the research results.

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[1]I am grateful for the thoughtful and informed replies to my inquiries about simulator motion provided by ("r" indicates those who also reviewed a draft of this report): R. Wade Allen (r), Paul W. Caro (r), Jack Dohme (r), Ralph E. Flexman, Charles Gainer, Dennis H. Holding (r), Ronald Hughes (r), Robert Kennedy (r), Jefferson M. Koonce (r), Gavan Lintern (r), Edward Martin (r), Elizabeth L. Martin, Grant McMillan (r), John E. Morrison (r), Gil Ricard (r), Gary Riccio, Stanley N. Roscoe (r), Paul J. Sticha (r), Clarence A. Semple (r), Edward A. Stark (r), Richard Vestewig (r), Wayne Waag, Walter W. Wierwille, and Dennis Wightman.

I am also grateful to many from whom I did not request information about simulator motion, but who were interested enough in my work to provide reviews: John A. Briggs, Stephen L. Goldberg, Edgar M. Johnson, Henry Jex, Donald R. Lampton, Norman E. Lane, William Marroletti, Betty E. Moorman, William C. Osborn, H. McIlvaine Parsons, Michael J. Singer, William D. Spears, Paul J. Tremont, and Albert Wimmel.

A part of the problem is that relevant information is scattered. That problem can be at least partially solved by a disinterested analysis of the arguments for and against simulator motion.

Purpose

One purpose of this review was to analyze the arguments for and against using simulator motion. Another purpose was to suggest ways for deciding whether to use force motion cuing and if so what kinds for various applications.

Method

Procedure

My colleague, Jim Bliss, made telephone calls that resulted in the National Highway Traffic Administration's doing a literature search for us. Results of the search indicated that no research had been performed on the effects of simulator motion upon transfer of training to automobiles, trucks, or other land vehicles.

During the literature search for effects of motion in land-vehicle simulators, I also began eliciting the views of persons who had done research with aircraft simulators. I wrote letters to friends and other researchers whose work I respect, asking them to:

1. Suggest journal articles, research reports, and other documents for me to read.

2. Recommend persons whose research or comments on the effects of motion they considered noteworthy.

3. Express their views on the conditions under which motion platforms, seat shakers, g-seats, stick shakers, and other means of motion cuing might be desirable or effective.

Respondents

The procedure summarized above resulted in my writing to 31 researchers. Twenty-four replied. The names of those who replied are in the footnote on page 1.

Reasons for Not Using Motion Platforms

Several of the researchers advised against the use of motion platforms. Their reasons involved:

1. Absence of supporting research results.
2. Possible learning of unsafe behavior.
3. Achievement of greater transfer by means other than motion cuing.
4. Undesirable effects of poor synchronization.
5. Direct, indirect, and hidden costs.
6. Alternatives to motion bases for producing motion cuing.
7. Benign force environments.

Absence of Supporting Research Results

Experiments on transfer from simulators to aircraft have produced no results that favor the use of motion bases (Sticha, Singer, Blacksten, Morrison, & Cross, 1990). The absence of supporting research results is a weak argument for not using motion platforms. It is a weak argument for three reasons, which involve (a) unknown motion characteristics, (b) unsafe tasks, and (c) statistical power.

Unknown motion characteristics. We know little about the characteristics of the motion used in transfer of training research. Ricard told me that research reports hardly ever contain data on the detailed performance characteristics of the motion used in the research. (Exceptions Ricard mentioned were reports on the NASA Langley simulator and the Navy's Visual Technology Research Simulator.) Sticha et al. (1990) reached a similar conclusion: Because the "fidelity" of motion systems is not typically mentioned in research reports, we know little about the quality of the motion whose effects have been reported. Sticha et al. (1990) concluded that finding no differential effects due to motion and no motion may simply suggest that no motion is no worse than bad motion. Elaboration of that point seems warranted because it applies to simulator research beyond the effects of motion.

For a variety of reasons, we are unlikely to find differences in transfer to parent equipment in comparisons of most military training alternatives (Boldovici, 1987). Declarations that such training alternatives are equally effective carry little meaning and seem Pollyanna-like. Knowing that something is as effective as something whose effectiveness is unknown does not reduce much uncertainty. And Sticha et al.'s reasoning suggests that when we find no differences as the result of training alternatives - motion and no motion, for example, or weapons systems and simulators - we may just as legitimately declare the alternatives equally ineffective as equally effective.

Unsafe tasks. McMillan's letter and Stark's letter included the observation that the very tasks upon which motion may have the greatest effect are tasks that are difficult to replicate in aircraft and are too dangerous to include in transfer of training research.

Edward Martin's reply to my letter included the comment that the tasks used in aircraft transfer of training experiments are "motion insensitive." The tasks are maneuver- or pilot-initiated tasks in stable, easy-to-control aircraft. In a related vein, Ricard and Parrish (1984), citing the work of Gundry (1976, 1977) and of Caro (1979), noted that, "Little seems to be gained by trying to simulate the motions a pilot deliberately creates" (p. 249).

Flexman's letter included, "Keep in mind that the measures used in transfer of training studies may not be sensitive to the contributions made by simulated motion. . . . I know of no instances where the development of sensitivity to or interpretation of motion cues was specifically taught prior to transfer studies."

Riccio wrote, "There is currently a bias against 'motion' in flight simulators because motion may actually be relatively unimportant in the current uses of flight simulators. Uses in which 'motion' would be important are currently not common in flight simulation."

Stark wrote, "We have been faced with this dilemma since the beginning of flight simulation: how to validate simulation and training designs without compromising cost and safety."

The implication for research with land-vehicle and aircraft simulators seem clear: In situ replication of only the safest scenarios used in practice is feasible. Demonstrating the effects of motion or of any other experimental treatment on unsafe tasks via transfer to parent vehicles is not feasible.

Establishing the effects of training-device characteristics, including motion, upon learning and performing unsafe tasks requires developing reliable alternatives to transfer of training experiments. The alternatives are part-task skill and knowledge tests and simulator based tests.

Nearly all unsafe tasks have component skills and knowledge that not only can be safely tested but also can provide strong indications about the extent to which unsafe tasks have been mastered. These facts provide the rationale for synthetic performance testing (Osborn & Ford, 1976). Component skills in recovering from emergencies, for example, might be tested using simulators and verbal (not necessarily written) tests. Component skills and knowledge may not be sufficient for proficiency in recovering from an emergency but strong logical cases can be made for their necessity.

Safe simulator based tests of emergency procedures might be developed along the lines suggested by the work of Ariel (cited in Moore, 1977): Digitized templates of ideal performance could be generated from videotapes of the performance of masters and from analyses of the mechanics required for optimal performance. Records of trainees' responses to emergency situations could be compared with the templates and the differences used as bases for prescribing remedial training.

Recent work by Lintern, Roscoe, and Sivier (1990) and by McMillan (mentioned later) with quasi-transfer experiments also represents a route to safe testing of emergency procedures and other unsafe tasks. Quasi-transfer experiments examine transfer from one device to another or to a reconfigured version of the first device. The results of such research may not carry much weight with military users of simulators, who may not know that reliability increases with the number of test items and with standardized test administration; and that a long, standardized, device mediated test will be more reliable than a shorter weapon-system test, even if the weapon-system test is standardized.

Measurement reliability is, of course, important for two reasons. One reason is that an unreliable test cannot be valid (Popham, 1981); that is, an unreliable test will not measure what we want it to measure. Reliability is necessary, but not sufficient, for validity; without reliability there can be no validity, but reliability does not guarantee validity. Those who insist that transfer to parent equipment is the only legitimate test of simulator effectiveness may be accepting unreliable test results that cannot be valid while rejecting reliable test results that may be valid.

Because of the need for measurement and because of the high costs and other disadvantages of transfer experiments, we would do well to act on Gagne's (1954) advice: "The concepts of reliability and validity are well known to psychologists. They appear to be applicable without change or reservation to the measurement of performance by means of a training device" (p. 99). The minimum requirement for following Gagne's advice is for researchers to report the reliability of the tests used in their research.

<u>Statistical power</u>. The second reason reliability is important is that it affects the power of statistical tests. Power is the probability of detecting true differences between groups; that is, of correctly rejecting the hypothesis that no differences exist between groups. Power increases with measurement reliability, because of decreased error variance. Inadequate statistical power is ubiquitous in military training research. Finding no differences as functions of treatments often seems virtually guaranteed, not because differences are absent, but because experiments lack power and are otherwise deficient (Boldovici, 1987; Morrison, 1990). In studying the effects of simulator motion, for example, researchers may use tasks that are variously

subject to motion effects, may train small numbers of subjects to minimally sufficient proficiency levels, may confound treatment effects by training to criterion, may measure transfer only on the first few trials, and may use unreliable mean differences as numerators in transfer formulas - characteristics that inhere in much simulator-to-aircraft transfer research.

Statistical power is relevant, not only for research that examines the effects of motion on learning flight skills, but also for research that addresses the question, "How much fidelity is enough?" Experiments designed to answer that commonly asked question are likely to take the following form: One group will use a "low fidelity" option during training. A comparison group will use a "high fidelity" option. The scores obtained by the two groups on a transfer test will then be compared. If no statistically significant differences are found between the two groups' scores on the transfer test, the low fidelity option and the high fidelity option will be declared equally effective. The declaration of equal effectiveness may then be used as justification for the lower fidelity training options - simulators, for example, in place of weapons systems. That line of thinking is specious. It rests on the assumption that finding no difference was caused by the absence of differences. An assumption more in line with military transfer research is that finding no difference between the result of training with simulators and the result of training with weapons systems is caused by insufficient statistical power and other experimental deficiencies.

Insufficient statistical power is a plausible hypothesis for explaining the preponderance of null results in military transfer of training experiments. Holding reminded me however, "Willingness to accept the null hypothesis may reflect the fact that any motion effects are very small." Holding's reminder was reminiscent of Roscoe's (1980) assessment of the size of motion effects: "Complex cockpit motion, whether slightly beneficial or detrimental on balance . . . has so little effect on training transfer that its contribution is difficult to measure at all" (p. 216). One implication here is as Sticha et al.'s (1990) thinking suggested: The experimental treatment, motion, may simply be no worse than an inadequate alternative, no motion. Another implication is that researchers who investigate small effects should consider reporting the results of power tests to estimate the minimally sufficient numbers of subjects required to demonstrate effects that may in fact exist.

Regardless of differing opinions about the causes of null results, the argument for not using motion platforms because results do not demonstrate benefits remains untenable. Null results can ensue from factors other than the absence of differences between motion and no-motion treatments. Finding no differences in transfer due to simulator motion and no motion demonstrates only that we found no differences. Finding no differences demonstrates nothing about the effects of motion and no motion.

Possible Learning of Unsafe Behavior

In response to Gebman et al.'s (1986) claim that motion systems would be necessary to teach C-17 engine-out recovery procedures, Lintern (1987) observed,

> some dangerously muddled thinking. . . . If motion is important for alerting pilots to, or for helping them recover from, a critical situation such as loss of engine thrust, there is no evidence that the motion systems to be provided for the C-17 training system will teach pilots the essential sensibilities. This is a truly dangerous possibility. Operational personnel are likely to assume that the motion system is doing its job when it is not, and the failure may become apparent only from an incident in which a pilot does not recover successfully from a loss of engine thrust (p. 1).

Lintern's argument about not knowing what unsafe behavior motion systems promote learning seems compelling. The argument is insufficient justification for exclusive use of fixed base systems, however, because equally compelling arguments can be made against the use of fixed base systems; namely:

1. Learning unsafe behavior may be promoted by fixed base simulators.

2. Training with motion platforms may have salutary effects on pilots' ability to deal with emergency procedures.

3. Training with fixed base simulators may promote learning more unsafe behavior than training with motion based simulators.

Implications seem clear: Specify training objectives. Then hypothesize ways that particular simulator characteristics, motion bases or fixed bases, for example, might promote learning that would prove counterproductive in the parent vehicle. Doing so is without question an art form that requires considerable familiarity with both the simulator and the parent equipment and with sufficient conditions for learning.

Morrison and Hoffman (1988) applied such methods in analyzing the strengths and weaknesses of several tank-gunnery training devices. Their methods are considerably more useful than the so-called "task coverage analyses" that characterize the design and evaluation of Army training devices. The usual "task coverage analysis" is performed by asking operators whether they can perform various tasks in the training device, without regard for sufficient stimulus conditions for learning. Ignoring sufficient stimulus conditions for learning can lead to ludicrous results. Because an interpreter can write in two languages with a pencil, for example, would a "task coverage analysis" indicate that the pencil was a sufficient medium for teaching the two languages?

Morrison and Hoffman's method involves identifying differences between stimulus-response relations in the devices and corresponding S-R relations in the parent vehicle. For each training objective where differences are found, the researchers make educated guesses about the effects of those differences. The results lead to strong inferences about how to improve devices and their use. Morrison and Hoffman's (1988) analyses revealed, for example, that although the Army's main tank-gunnery training device provides a medium for practicing some tasks involved in degraded mode gunnery, none of the training requires recognizing the conditions that signal the need for performing degraded mode gunnery. Such methods obviously are inappropriate for teaching procedures in which recognizing the conditions under which they are to be performed is as important as performing the procedures.

Achievement of Greater Transfer by Means Other Than Motion Cuing

Semple and others suggested independently that motion cuing was less cost-effective than other methods for achieving transfer. Lintern, for example, wrote, "I would put my money elsewhere." Roscoe's letter included, "What puzzles me is why we continue to give so much attention to the motion problem, which is easily avoided, when so much actual transfer benefit is available for almost nothing through the adaptive augmentation of even the simplest computer-animated visual system."

Various formulas for measuring relative amounts of transfer (Gagne, Foster, & Crowley, 1948) have been modified to reflect costs in terms of numbers of trials, amounts of training, or dollars. Lawrence, for example, described several transfer efficiency measures in 1954. Povenmire and Roscoe (1971) introduced the Transfer Effectiveness Ratio, which was later elaborated by Roscoe (1971a, 1971b). Requisite to all measures of transfer efficiency is some measure of transfer; that is, an estimate of the difference between an experimental group's score and a comparison group's score referenced against the comparison group's score or against the maximum possible gain. For reasons discussed throughout this article, the measures of transfer necessary for performing transfer-efficiency analyses may not be available. Because no transfer results show motion benefits, transfer-efficiency analyses can only show no benefits at any cost. Cost-effectiveness results that favor motion are therefore not forthcoming. Even if generating cost-effectiveness estimates empirically were possible for all tasks, doing so would be prohibitively time-consuming in the context of device-development schedules. Stark wrote,

> I feel there isn't time nor, in fact, the need to do the basic research needed in applying sound scientific principles; Boff has already shown us the galaxy-sized gaps in the available data. On the other hand, there is a tremendous body of insight,

if it could be organized, on what is likely to be needed, and what isn't.[2]

Precise cost-effectiveness estimates are not necessary, however, to appreciate Lintern and Roscoe's position: We do not have evidence for the effectiveness of motion platforms. Roscoe and Lintern have demonstrated the effectiveness of adaptive and augmenting techniques. But rather than implement the proven instructional techniques, we choose to debate the merits of unproven engineering features.

Undesirable Effects of Poor Synchronization

Poor synchronization among motion cues, visual cues, and control inputs may lead to learning unsafe or other counterproductive behavior. Additional undesirable effects of poor synchronization include the possibility of simulator sickness and instructors' not using available motion systems. Kennedy hypothesized, "The closer one gets to physical fidelity without actually getting there, the more 'simsick.'" Waag noted that pilots prefer no motion to poor motion. Roscoe (1980) wrote, "The most costly motion systems are routinely turned off most of the time during training" (p. 215). Koonce's reply to my letter included, "The Air Training Command purchased motion systems for its new undergraduate pilot training (UPT) in the late seventies and early eighties. Now that those who were so 'high' on motion have moved on, the pilots (instructors) consistently fly the simulators with the motion systems OFF!"

Vestewig and others told me about cases in which instructors turned off motion bases during aircraft simulator exercises without students noticing the difference.

The incidents mentioned above are about motion systems that are at least 10 years old. Allen's letter included the observation that, "Computational and cueing device capability have steadily improved in the past few years, and current technology should be capable of minimizing cueing artifacts, at least in regard to ground vehicle simulation."

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[2]The optimization modeling work begun by Sticha et al. (1990) is an attempt to organize the body of insight, not only for simulator motion, but also for other aspects of simulator design. Sticha et al.'s work holds promise for providing the kinds of cost-effectiveness estimates necessary for trading off engineering features such as motion platforms against instructional methods such as adaptive training.

Vestewig told me that he thought the state of the art had improved to the point where synchronization might not be a problem in land-vehicle simulation. With regard to aircraft simulators, Stark and Koonce were not so sure. Stark wrote, "The problem of cue coordination and the associated cue delay problem are both crucial and severe." Koonce observed, "Those who have a vested interest in motion say . . . BUY more and better motion systems to replace the inadequate ones that are not being used properly." Roscoe rebutted that selling point in 1980, noting,

> The presence and type of motion have relatively little effect on transfer effectiveness in comparison with such variables as procedural fidelity, the presence and type of visual system, the reliability and availability of properly operating equipment, and how the device is used in the training program (p. 216).

Direct, Indirect, and Hidden Costs

> The life-cycle costs associated with state-of-the-art motion capabilities are not limited to the relatively modest cost of the motion platform itself nor even to the cost of the building, its heating, and air conditioning. . . . Indirect costs associated with high, complex accelerations are greater than the direct costs. Everything in the simulator has to be ruggedized. Instruments, in effect . . . have to be flight qualified. . . . Even greater hidden costs are associated with the design, development, and maintenance of computer hardware and software to coordinate the gyrations of the cockpit with the visual indications by transforming the equations of aircraft motion into driving signals for six hydraulic actuators (Roscoe, 1980; p. 201).

Wightman's reply and Semple's reply also emphasized the importance of considering the hidden and collateral costs of motion systems.

As for housing requirements, Roscoe (1980) wrote, "To double the duration of a given rate of change in acceleration requires eight times the distance in each dimension and thus a building 512 [= 8 x 8 x 8] times larger" (p. 201).

Alternatives to Motion Bases for Producing Motion Cuing

The obvious difficulty in selecting alternatives to motion bases is in identifying the required cues or discriminative stimuli that are sufficient for learning. Vestewig advised, "Keep kinesthetic cuing but not necessarily motion platforms, especially if the former can be done cheaply."

Dohme wrote, "Based on the IP [instructor-pilot] questionnaire data from our transfer-of-training work . . . we have decided we need a seat shaker operating (modulated by aircraft speed and condition)."

Edward Martin wrote, "G-seats can be very effective in substituting information which would be available from whole-body motion, but do not appear to be very promising as training devices."

McMillan elaborated Edward Martin's point:

> We have . . . evaluated [g-seats'] ability to provide roll and pitch cues, rather than sustained force cues. . . . They can do this very effectively if they have good response characteristics (bandwidth and low time delay). However, our transfer of training from g-seat to platform motion has not been nearly as effective. Based upon our research, and that of others, I believe that any kind of motion cuing is only going to improve <u>performance</u> if the controlled vehicle has marginally stable dynamics, or if the task requires one to detect and respond to external disturbances (turbulence, wind shear, loss of a control surface, change in vehicle dynamics/control characteristics). Because many of these disturbances are unsafe, or difficult to control (reproduce) in an actual transfer of training test, it may be almost impossible to show <u>training</u> benefit for this type of motion cuing.

<u>Benign Force Environments</u>

Vestewig wrote,

> The motion forces on ground vehicles are so much more benign than those . . . in high performance fighter aircraft that they can probably be captured well by the pitch and tip of motion platforms. By the same token, the motion may not add any training value since the movement <u>is</u> relatively benign, and the driver does not use the g-force cues to direct his actions as he does in a fighter aircraft.

Riccio wrote, "Motion systems are probably less important in more benign force environments; for example, landing, altitude control, some forms of formation flight, procedures training." Some forces involved in land-vehicle driving may not be benign. Semple recounted his impressions after driving a Marine amphibious landing craft "over some of the worst terrain I ever have experienced. I concluded . . . no simulator could portray the motion I experienced."

Reasons for Using Motion Platforms

Although several of the researchers mentioned conditions under which motion might improve transfer, nearly all acknowledged the absence of supporting evidence. Roscoe, for example, noted that vertical accelerations may have some transfer value in mimicking "rough air." He immediately added, "I know of no experimental evidence for this view."

Possible reasons for the absence of evidence in support of motion effects on transfer to parent equipment were discussed earlier: unknown motion characteristics, safety considerations, and inadequate statistical power.

The reasons given by the researchers in support of using motion platforms involved:

1. Reducing the incidence of simulator sickness.

2. Low cost.

3. Users' and buyers' acceptance.

4. Trainees' motivation.

5. Learning to perform time-constrained, dangerous tasks.

6. Motion as a distraction to be overcome by practice.

7. Application of adaptive or augmenting techniques.

8. Inability to practice some tasks without motion.

Reducing the Incidence of Simulator Sickness

Gainer, who is an aviation psychologist and a fixed-wing pilot, mentioned that flying fixed base simulators makes him nauseous. Semple et al. (1981) wrote, "This condition [simulator sickness] is rare, but sometimes occurs when realistic visual cues are presented without the motion cues which normally would accompany them in the real world" (p. 130).

Cue conflict issues were elaborated by Reason (1974), who described six ways to induce sickness: visual stimulation without inertial (vestibular and non-vestibular position sense) stimulation, inertial stimulation without visual stimulation, asynchrony between visual and inertial stimulation, otolith stimulation without semi-circular canal stimulation, semi-circular canal stimulation without otolith stimulation, and canal-otolith conflict.

Avoiding cue conflict was one of the reasons given by Gebman et al. (1986) for proposing to use motion platforms in the C-17 flight simulators. Lintern (1987) took issue, not only with the ability of motion to reduce simulator sickness, but also with the role of cue conflict as a causal agent:

> The cue-conflict theory. . . . fails to account for a good number of nauseogenic and disorientation phenomena that are associated with vehicular motion, bodily movement, and visually induced apparent motion. . . . The data of Ryan, Scott, and Browning (1978) . . . show no tendency toward sickness with motion systems on or off (p. 2).

Additional support for the view that simulator motion does not reduce simulator sickness is in the U.S. Naval Training Systems Center's (1988) Simulator Sickness Field Manual Mod 3: "If all else fails, turn off the motion base or the visual scene" (p. 7).

Kennedy and Fowlkes (1990) noted that the infrequency of simulator sickness requires researchers to examine the role of statistical power in producing results. One implication of Kennedy and Fowlkes's thinking is that experimental examinations of the effects of motion upon simulator sickness may require such large numbers of subjects that definitive research on the role of motion in simulator sickness may never be conducted.

Another implication of Kennedy and Fowlkes's thinking involves the baseline against which simulator sickness should be compared. One wonders, for example, how the incidence of sickness in simulators compares with the incidence of sickness in parent equipment. Without data on the amount and quality of that difference, objective assessments of the extent and the importance of simulator sickness will remain difficult.

Identifying points of diminishing returns, at which additional investments in "fidelity" stop yielding commensurate reductions in simulator sickness, is a deceptively attractive goal that is unlikely to be achieved for various reasons. The reasons include the multidimensionality of "fidelity" and attendant measurement problems, small effect sizes and concomitant requirements for large numbers of subjects, and the impossibility of establishing causal relations with null results.

Low Cost

Low cost was one of the points made by Gebman et al. (1986) in support of motion platforms for the C-17 simulator. Lintern's rebuttal (1987) was that, although the cost per motion system was estimated at 6%

of the total simulator costs, the 6% did not include some related costs, "such as an approximately 10-times larger building, with corresponding air conditioning and fire suppression systems; a vast increase in high-speed computing requirements and software; and ruggedizing everything on the platform to withstand the jolts of the motion system (p. 2)." Lintern concluded, "No matter how quickly I say it, $3 million per simulator sounds like a lot of money. . . . a considerable waste if the purchased item is of no value" (p. 2).

The direct and indirect costs of motion bases may be smaller for land-vehicle simulators than they are for aircraft simulators. Evans and Sutherland, for example, has designed a 3-degrees-of-freedom truck driving simulator that will cost less than a million dollars (Welles, 1990). The 3 dof are longitudinal acceleration, lateral acceleration, and yaw. The motion is electrically rather than hydraulically driven, and the cab is suspended in a way that allows it to pitch and roll in response to motion in the three other axes. The device occupies an area less than 20 feet square. One wishes that evidence of transfer accompanied such advances. But on whom shall the burden of proof rest? On vendors who are trying to broaden their markets by producing affordable devices? On users and buyers who may not distinguish between evidence of effectiveness and bad research? Or on researchers who confuse null results with proof of equal effectiveness?

Users' and Buyers' Acceptance

The issue of user acceptance was another of the reasons given by Gebman et al. (1986) for proposing motion bases for C-17 simulators. Lintern (1987) rebutted Gebman et al.'s (1986) user-acceptance argument on the grounds that,

> The argument gives little credit to the professionalism and intelligence of our military pilots. While we can expect pilots to express a preference for motion systems, any initial negativity resulting from their absence is likely to erode if the device in question is both reliable and effective, albeit somewhat lacking in aircraft features. To the question of whether they would prefer something that is enjoyable to something that is effective, I suspect that most military pilots would opt for usefulness (p. 2).

Lintern has done a neat job of painting dissenters into a corner. Arguing against the professionalism, the intelligence, and the preference for effectiveness over enjoyment that he mentions is not a good way to win friends and influence pilots. Gebman et al.'s point remains nonetheless unequivocal: Many users and buyers do demand motion bases. Why this is so is clearer in some cases than in others. The highly experienced user-pilots at FAA were so adamant in their demands, for example, that motion bases are now federally mandated. The soon-to-become experienced users of the M1 tank-driver trainer also have required a motion base. I suspect that requirement did not result from choosing between a device that would be enjoyable and a device that would be effective. The choice was between a fixed base trainer and a motion based trainer with no evidence of superiority for one or the other.

Users and buyers usually are not versed in the results of research on motion vs. no-motion. Few distinguish between good research and bad; that is, between results caused by training alternatives on the one hand, and results caused by errors in experimental design, execution, analysis, interpretation, and reporting on the other. Users and buyers also may know little about sufficient conditions for learning; they may not consider the role of stimulus-response relations in learning or the necessity of control groups for valid causal inference. Understanding the utility of motion and no motion requires an understanding of causes of research results that many users and buyers do not have. Vestewig's comment on this state of affairs was noteworthy because it reflected a clear sense of responsibility:

> I think the paucity of convincing results . . . reflects on us as researchers; if we cannot come up with more compelling results and methods for presenting them to the research and user community at large, then maybe we should acquiesce to the users and supply them motion bases whenever they want them.

As for savings, military buyers and users may not be as impressed as researchers would like them to be by price comparisons between devices with and without motion bases. Job-advancement incentives may promote association with high-priced, high-tech projects; and incentives may be greater for justifying next year's budget than for buying the least expensive device that is likely to get the job done.

Trainees' Motivation

The issue of trainees's motivation arises, not only in the context of motion platforms, but in other areas of military training as well. Military training media that share characteristics with video games, for example, are said to be motivating because enlisted men have experience playing video games. Books and lectures are said to be not very motivating for reasons that need not be elaborated here. Underlying such contentions seems to be a line of thinking that says, "If trainees don't like the training medium, they won't use it." That line of thinking seems appropriate in designing video games for a shopping mall. But the object of military training is not to promote commercial success by keeping players "motivated." The object of military training is to promote learning skills that are important in combat. Military organizations can motivate trainees without using simulators that are fun.

Another reason for dismissing considerations about how much trainees like training and devices is that motivation is only important if it affects transfer to parent vehicles. We have no evidence for differential effects of fixed base and motion based simulators on transfer to parent vehicles. Until such evidence is forthcoming, there seems little reason for concern about the effects of simulator motion on trainees' motivation.

Holding raised a substantive motivational issue: "Some kind of motion, or even a loosely sprung seat, might be desirable simply to 'shake the trainee's faith' that he is operating in a rigid environment." Holding's comment has implications for state dependent learning. Suppose, for example, that trainees in simulators are in relaxed or other emotional states different from the emotional states they will experience while operating parent vehicles. Will those differences affect acquisition, transfer, and retention? If so, how?

Learning to Perform Time-Constrained, Dangerous Tasks

Caro mentioned that motion may be important if it provides an alert that increases the amount of time an operator has for responding to emergencies. Stark wrote, "Non-visual cues are important because (1) they tend to be perceived and used before there is time to analyze correlated visual cues, (2) they don't require a specific focus of attention, (3) they tend to be available when visual cues are temporarily absent."

The use of force motion cuing seems appropriate in training for all cases in which motion provides an alert and in which small differences in available time make the difference between disaster and a safe recovery. An example for automobile- or truck-driving training might be responding to a front tire blowout in the face of oncoming traffic. At the risk of belaboring the obvious, I repeat that safety considerations prevent including some tasks in transfer of training experiments.

Motion as a Distraction to Be Overcome by Practice

Caro mentioned uncorrelated disturbance motion as a possible condition under which motion platforms might be useful.

Roscoe wrote, "Vertical accelerations provided by seat shakers to mimic 'rough air' may have transfer value, because turbulence makes flying harder."

Holding gave an example of tasks that may be easy to perform without motion and impossible to perform with motion:

> If you find that vibration at, say, 3-4 Hz is particularly inimical to visual acuity, it means that a trainee on a static simulator will suddenly find he cannot do a vernier task when he transfers to the real equipment. Thus, <u>use a motion platform</u> (at the right frequency) <u>if</u> the task involves heavy visual demand.

Vestewig recounted a conversation with airline pilots and instructors about how they used their motion based simulators: "The motion bases were of greatest value in training emergency procedures. With the entire cockpit bucking and shaking violently, the crew members' tasks of simply finding and manipulating knobs and dials, to say nothing of the stick and pedals, was much more difficult."

Riccio's letter included the observation that,

> "Motion" systems should be important in any situation that involves significant changes in the velocity vector of the simulated vehicle. Changes in the velocity vector are significant whenever they are relevant to the flight task; for example . . . control of aircraft attitude, visual and manual tasks in the cockpit that are frustrated by uncontrolled movements (perturbations) of the crewmembers' bodies.

Lintern (1987) noted that because "pilots sometimes need to ignore information provided by the inner ear, it may be advantageous to train without motion" (p. 1). That may be true during some stages of learning. But during other stages, training with motion would seem equally advantageous.

Practicing tasks under conditions of severe vibration and of other distracting motion effects seems a good reason for using motion bases in simulators. The extent to which such practice would be necessary or desirable either in aircraft simulators or in land-vehicle simulators depends entirely upon what one wishes to teach. Whether sufficient cuing might be provided by seat shakers, g-seats, and other alternatives less expensive than motion bases is an interesting research question that for reasons mentioned earlier cannot be answered by experimental examinations of transfer from simulators to parent vehicles.

Application of Adaptive or Augmenting Techniques

Flexman mentioned that "motion can be helpful if we can enhance the usefulness of motion cues." Caro wrote, "Simulating only the motion element that provides the cue could expedite the development of experts." These concepts relate to adaptive training techniques, which Lintern and Roscoe also mentioned.

A central concept in adaptive training is to increase the salience of discriminative stimuli or reinforcers during early practice (Boldovici, in press). For example, one might enhance the usefulness of force motion cues as Flexman suggests by augmenting or supplementing discriminative stimuli. One also might increase the salience of discriminative stimuli by isolating cues as Caro suggests.

Implementing adaptive procedures presents two problems. The first is to isolate discriminative stimuli. Lintern et al. (1990) seem to have done so for landing fixed-wing aircraft. Continuation and expansion of analyses to isolate discriminative stimuli would produce fruitful alternatives to shotgun approaches to simulator "fidelity" and, one hopes, put an end to vague, unsupportable speculation about how much fidelity is enough.

The second problem is that, according to Adams (1987), adaptive training has not proved superior to criterion practice for teaching motor skills. The null results of comparisons between adaptive and criterion practice are, however, as easy to explain as the null results of comparisons between practice with and without motion in flight simulation:

> [Adaptive] techniques will be more effective than practicing criterion behavior only with tasks that are difficult to learn. Selecting tasks for laboratory study on the basis of manageability may stack the cards against adaptive techniques. The crucial test would be one which used a task whose initiating [discriminative] or maintaining stimuli were of such low salience that the task could not be mastered by criterion practice alone (Boldovici, in press, p. 16).

Roscoe's suggestion for elaborating that point was,

> Because acceleration cues in flight tend to be of low salience, their enhancement in a simulator to induce correct responses (good habits) followed by gradual withdrawal to avoid developing a dependency on the enhanced motion cues, would be a prime candidate to demonstrate the potential value of cockpit motion.

Inability to Practice Some Tasks Without Motion

To now we have seen three kinds of situations in which motion may have salutary effects on transfer:

1. The motion creates distractions or is a source of task difficulty that one must learn to ignore or overcome during task performance (Caro, Holding, Riccio, Roscoe, Vestewig).

2. The motion provides an alert that gives the operator more time to perform tasks that are time constrained and dangerous (Caro).

3. Some conditions of acceleration: "significant changes in the velocity vector" (Riccio), for example, and "vertical acceleration of the whole cockpit . . . for the G-forces encountered in steep turns, stall entries and recoveries" (Roscoe).

Conditions of acceleration and force motion cuing to provide an alert are incorporated in Sticha et al.'s (1990) decision-support system for designing cost-effective training devices. Sticha et al.'s system, developed for making trade-offs among training alternatives for the AH-1 Helicopter, is called "Optimization of Simulation-based Training Systems" (OSBATS).

OSBATS includes a rule base for determining whether any of five means for force cuing will be required: a g-seat, a seat shaker, a 3-dof motion platform, a 5-dof platform, or a 6-dof platform. For each training objective, the OSBATS user must answer questions about:

1. Whether longitudinal acceleration, lateral acceleration, vertical acceleration, yaw, pitch, and roll are moderate or great.

2. Whether a motion cue initiates a response to an emergency procedure.

3. Whether a visual cue is correlated with motion cues that initiate task performance.

4. Whether the objective in question is a continuous control task.

5. Whether accelerations or decelerations are prolonged over several seconds.

My colleagues, John Bailey and Mike Singer, summarized Sticha et al.'s motion rules in Tables 1 and 2, which show the conditions under which OSBATS recommends each motion cuing alternative. A recommendation ensues only if at least one of the conditions in each of the three major sections of Table 1 applies. A recommendation for a seat shaker, for example, requires (1) moderate to high longitudinal acceleration, vertical acceleration, pitch, or roll; and (2) motion cues that initiate an emergency procedure or have no correlated visual cue; and (3) continuous control movement.

TABLE 1

Summary of Sticha et al.'s (1990) Rules for Choosing Among Seat Shakers, G-seats, and Motion Platforms for Rotary Wing Aircraft Simulators

	MODERATE TO HIGH LONG ACCEL	LAT'L ACCEL	VERT ACCEL	YAW	PITCH	ROLL	INITIATE EMERG'CY PROCED	NO CORREL'D VIS CUE	CONTIN CONTRL MOV'T	PROL'D ACCEL'N OR DECEL
SEAT SHAKER	X		OR X		OR X	OR X	AND X	OR X	AND X	
G-SEAT	X		OR X		OR X	OR X	AND X	OR X	AND X	AND X
PLATFORM (DOF IN TABLE 2)		X	OR X				AND X	OR X		

TABLE 2

Summary of Sticha et al.'s (1990) Rules for Choosing Among 3-Dof, 5-Dof, and 6-Dof Motion Platforms for Rotary Wing Aircraft Simulators

	MODERATE TO HIGH LONG ACCEL	LAT'L ACCEL	VERT ACCEL	YAW	PITCH	ROLL	INITIATE EMERG'CY PROCED	NO CORREL'D VIS CUE
3 DOF				X	OR X	OR X	AND X	OR X
5 DOF		X	OR X				AND X	OR X
6 DOF	X						AND X	OR X

Table 1 shows that a recommendation to use any kind of force motion cuing requires that the cue initiate a response to an emergency procedure or not have a correlated visual cue. Psychologists will recognize such cues as Skinner's discriminative stimuli, which set the occasion for a response, increase its probability, and in the absence of which a given response is unlikely.

Allusions to discriminative stimuli were interspersed in many of the researchers' replies. Caro, for example, asked, "Does the motion permit the operator to discriminate between conditions that otherwise could not be distinguished?" Morrison wrote, "Use motion if it is an important cue for performance. . . . not to simulate 'background' stimuli."

Semple noted, "Motion was a valuable training cue primarily when it was a main cue that was not available otherwise." Semple also asked, "How important is motion as a unique cue to control performance? If it is indeed unique, and wrong responses could be learned without it, then motion likely has value." And Elizabeth Martin asked, "Do any cases [of motion] provide non-redundant information?" Those replies suggest functions of motion beyond onset cuing. The researchers' mention of concepts such as control and information suggests that motion cues may serve reinforcing functions as well as discriminative functions. The same cue may, in fact, serve both as a discriminative stimulus and a reinforcer (Parsons, 1982).

Table 1 also shows that a recommendation for any kind of motion platform requires, not only that the cue initiate an emergency procedure or not have a correlated visual cue, but also that lateral accelerations or yaw be moderate or great. Those requirements, unlikely for most tasks, must be accompanied by an additional requirement - moderate or great longitudinal acceleration - for Sticha et al. to recommend a 6-dof platform (Table 2).

For reasons discussed throughout this report, any recommendation for a motion platform will receive no support from research on transfer to parent vehicles. Some researchers nevertheless continue to reject recommendations for simulator motion on the grounds that supporting transfer data do not exist. In his rebuttal of Gebman et al.'s (1986) recommendation for motion in practicing engine-out recovery, Lintern (1987) wrote,

> Transfer of training is the central issue. Do students taught with the motion system under consideration experience any substantial advantage in transfer to the aircraft when compared to students taught without the motion system? The only way out of this dilemma is to conduct the appropriate transfer study. If that is done prior to the development of . . . simulators, it may be discovered that motion systems are unnecessary, or that they are necessary and do the training that is intended, or that they are necessary but that something else is also required to complete the training. Any one of these findings is quite acceptable; what is not acceptable is to pretend we know the answer when it is apparent we do not (p. 1).

The words after the semi-colon are among the wisest I have read. As for accepting a finding that motion systems are unnecessary, would not doing so constitute pretending to know the answer when we do not? Would not accepting such findings perpetuate the myth that finding no differences proves none exist?

Conclusions

1. Research results on transfer of training from simulators to parent vehicles are insufficient to support decisions about whether to buy motion systems for vehicle simulators. That problem will not be solved by additional research on transfer from simulators to parent vehicles.

2. Research to date suggests that greater transfer can be achieved by less expensive means than by the use of motion platforms. That is because some research has demonstrated transfer from fixed base simulators to aircraft and no research has shown superior transfer with motion bases than without.

3. Results that show no difference between the effects of motion and no motion on transfer to parent vehicles do not prove that no differences exist. Finding no differences may be due to insufficient statistical power and to other experimental deficiencies rather than to the absence of differences. Solving this problem requires that researchers report the results of power tests they have done to determine the number of subjects required to demonstrate treatment effects. Nothing, including "equal effectiveness" of fixed base or motion based simulators, is proven by results that show no difference.

4. Results that show greater transfer to parent equipment as the result of simulator motion than without do not exist. One reason that such results do not exist is that definitive transfer of training experiments cannot be done: The conditions under which simulator practice of dangerous tasks takes place may be unsafe or impossible to reproduce in situ. Solving this problem requires developing reliable tests for safely assessing operators' performance of dangerous tasks. Nothing is proven by the absence of research results.

5. Our chief research need is for developing reliable tests for safely assessing operators' performance of unsafe tasks. Synthetic testing methods (Osborn & Ford, 1976), part-task skill and knowledge tests, simulator based tests, and quasi-transfer experiments (Lintern et al., 1990) can yield performance measurement that is more reliable and therefore potentially more valid than tests that use parent vehicles. Capitalizing on the potential of the alternatives to testing in parent vehicles requires that researchers report the reliability of the tests used in their experiments. Without data on test reliability, we shall remain unable to assess the validity of inferences made from tests used in transfer of training research.

6. Cost-effectiveness analyses incorporate the results of transfer experiments, which for reasons that may be unrelated to the effects of motion, will show no benefits of motion. Cost-effectiveness analyses will therefore show no benefits of motion at any cost.

7. Training in motion based simulators may promote learning unsafe or other counterproductive behavior. The same is true for training in fixed base simulators. Determining the unsafe habits that motion bases and fixed bases cause students to learn and determining the safe habits that motion bases and fixed bases prevent students from learning are necessary if simulators are to be used for teaching dangerous tasks. Safety considerations prevent making such determinations with simulator-to-vehicle transfer experiments. Solving this problem requires using analytic methods such as those of Morrison and Hoffman (1990), which lead to strong inferences about simulator characteristics that might promote unsafe or other counterproductive learning.

8. The use of training devices or simulators for practicing tasks that will be performed only in benign force environments is a good reason for not buying motion platforms. The effectiveness of fixed base aircraft training devices for teaching skills that will be performed in benign environments has been demonstrated (Roscoe, 1980).

9. Avoiding negative effects on trainees' motivation is not a good reason for military purchases of motion bases. Motivation is important if it affects performance in parent vehicles. We have no evidence for differential effects of fixed base and motion based simulators on performance in parent vehicles. Arguments about the effects of motion on trainees' motivation are therefore gratuitous.

10. Avoiding simulator sickness is not a good reason for buying motion platforms. One of the ways the U. S. Navy (1988) recommends for reducing sickness is, in fact, to turn off a simulator's motion base. A criterion for sufficient motion "fidelity" as the point where no one experiences simulator sickness probably is unattainable, because some trainees get sick in parent vehicles as well as in simulators.

11. Users' and buyers' acceptance of a simulator or other training device is not a good reason for military purchases of motion bases. Users and buyers who are uninformed about the causes of research results with motion bases will, by definition, make uninformed decisions.

12. Incentives for buying expensive simulators may be greater than incentives for buying inexpensive simulators. Incentives may include the necessity to use expenditures in justifying simulator budgets, and the job-advancement possibilities that attend association with expensive, high-tech projects.

13. The possibility that some tasks cannot be practiced under some conditions without force motion cuing is a good reason for choosing among seat shakers, g-seats, and motion bases. In the absence of transfer of training results to support any of those options, I recommend using analyses to identify discriminative stimuli for task performance. Analyses to identify discriminative stimuli are embodied in Sticha et al.'s (1990) motion rules. The rules summarized in Table 1 for choosing among a seat shaker, a g-seat, and a motion platform seem applicable to land-vehicle simulators as well as to helicopter simulators. In the unlikely event that application of those rules indicates the need for a motion platform, then the only remaining decisions are how many degrees of freedom and in which axes. Sticha et al.'s rules, summarized in Table 2, seem to be the only codified guidance for choosing among 3-dof, 5-dof, and 6-dof. Those rules should be viewed as working hypotheses and used subject to modification in light of additional analytic and ultimate empirical identification of discriminative stimuli for helicopter operations. For land-vehicle simulators, the minimal dof requirements (actuated longitudinal acceleration, lateral acceleration, yaw, with suspension that allows pitch and roll) suggested by Welles (1990) also should be viewed as working hypotheses and used subject to modification in light of analytic and empirical identification of discriminative stimuli.

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